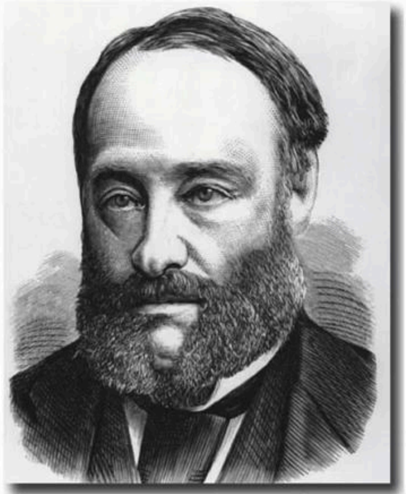
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

RESCIF
Réseau d'excellence des sciences de l'ingénieur de la Francophonie

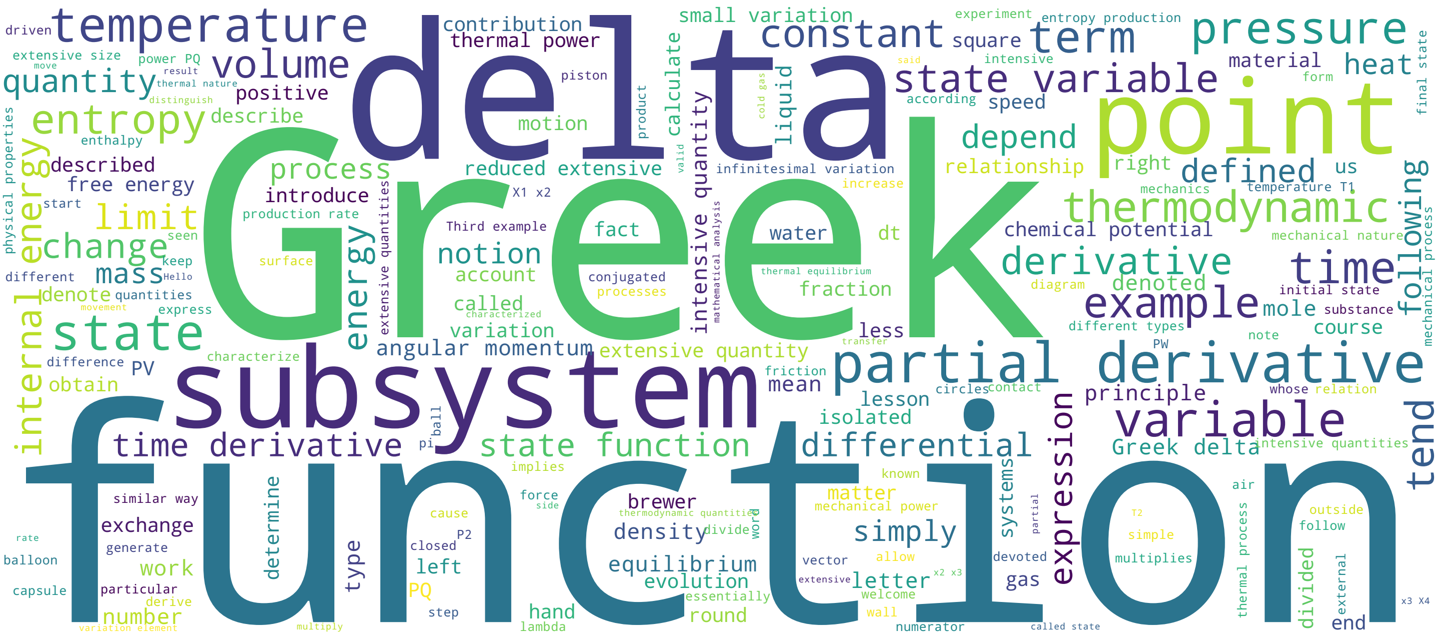
Thermodynamique

Etat, grandeurs et différentielle

Dr. Sylvain Bréchet

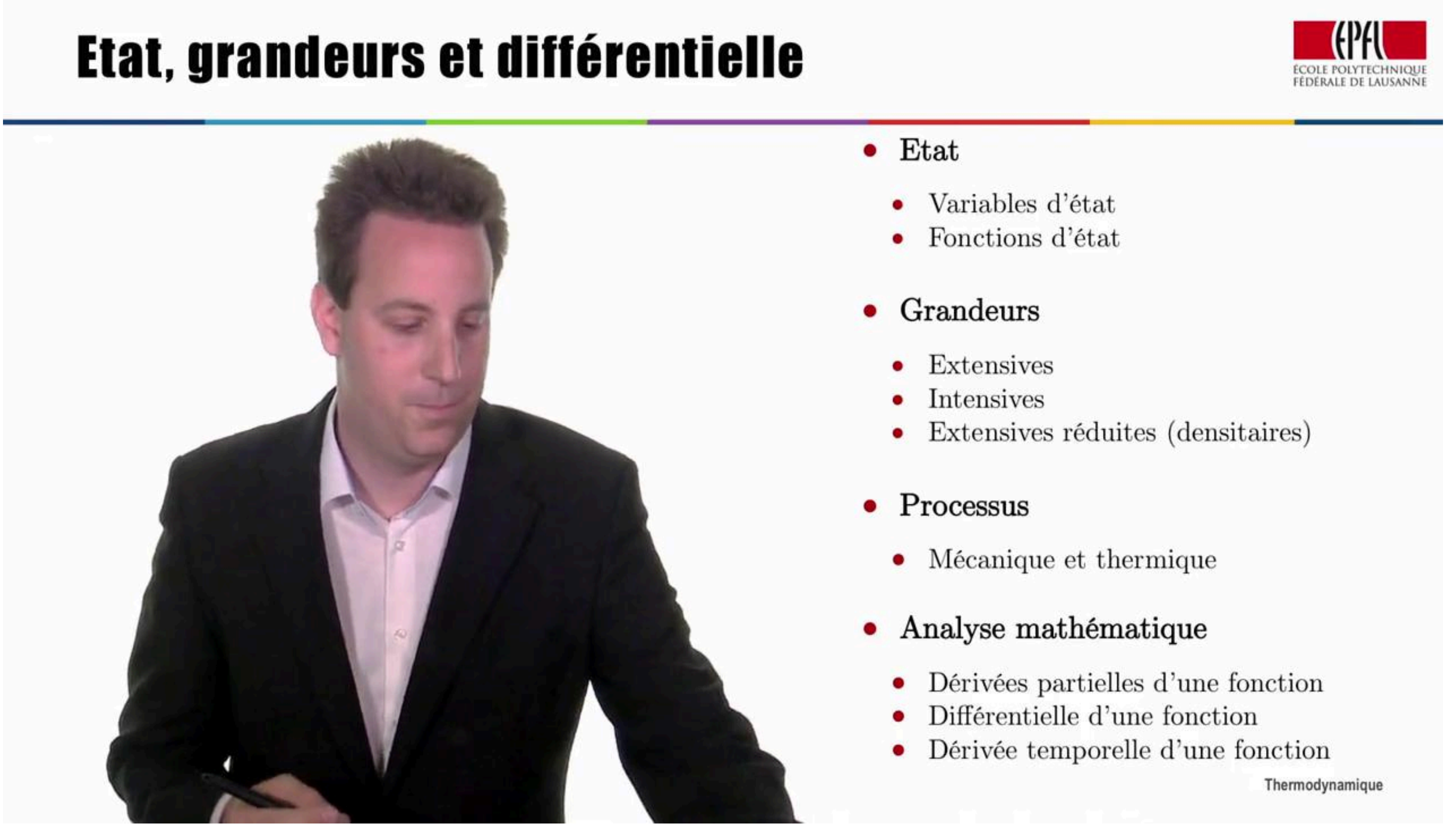


James Prescott Joule, 1818 - 1889



Video

EPFL

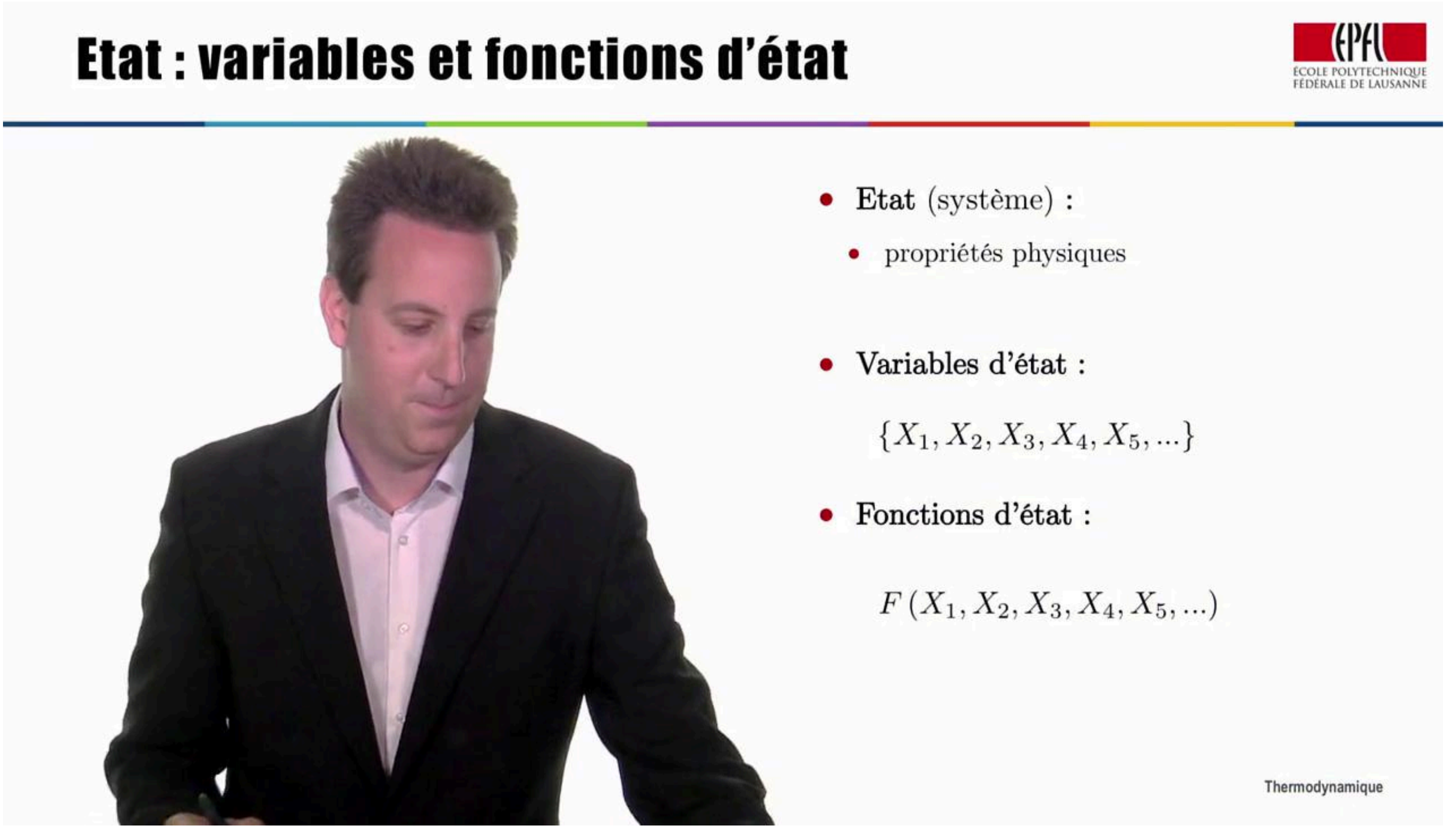


Hello and welcome to this word of thermodynamics. My name is Sylvain Bréchet and I am a lecturer in physics at PFL. In this course, we will first define the state of a thermodynamic system and to do so, we will introduce the notions of state variable and state function. In a second step, we will see that there are different types of thermodynamic quantities. These quantities can be extensive intensive or extensive reduced. This is also known as density size. Thirdly, we will define the notion of process. We will see that there are two types of processes mechanical processes on the one hand, and thermal processes on the other hand. And to finish, we will indulge in a little of mathematical analysis to define the partial derivatives of a function. The differential of a function is the time derivative of a function.

Notes

Summary

0m 05s

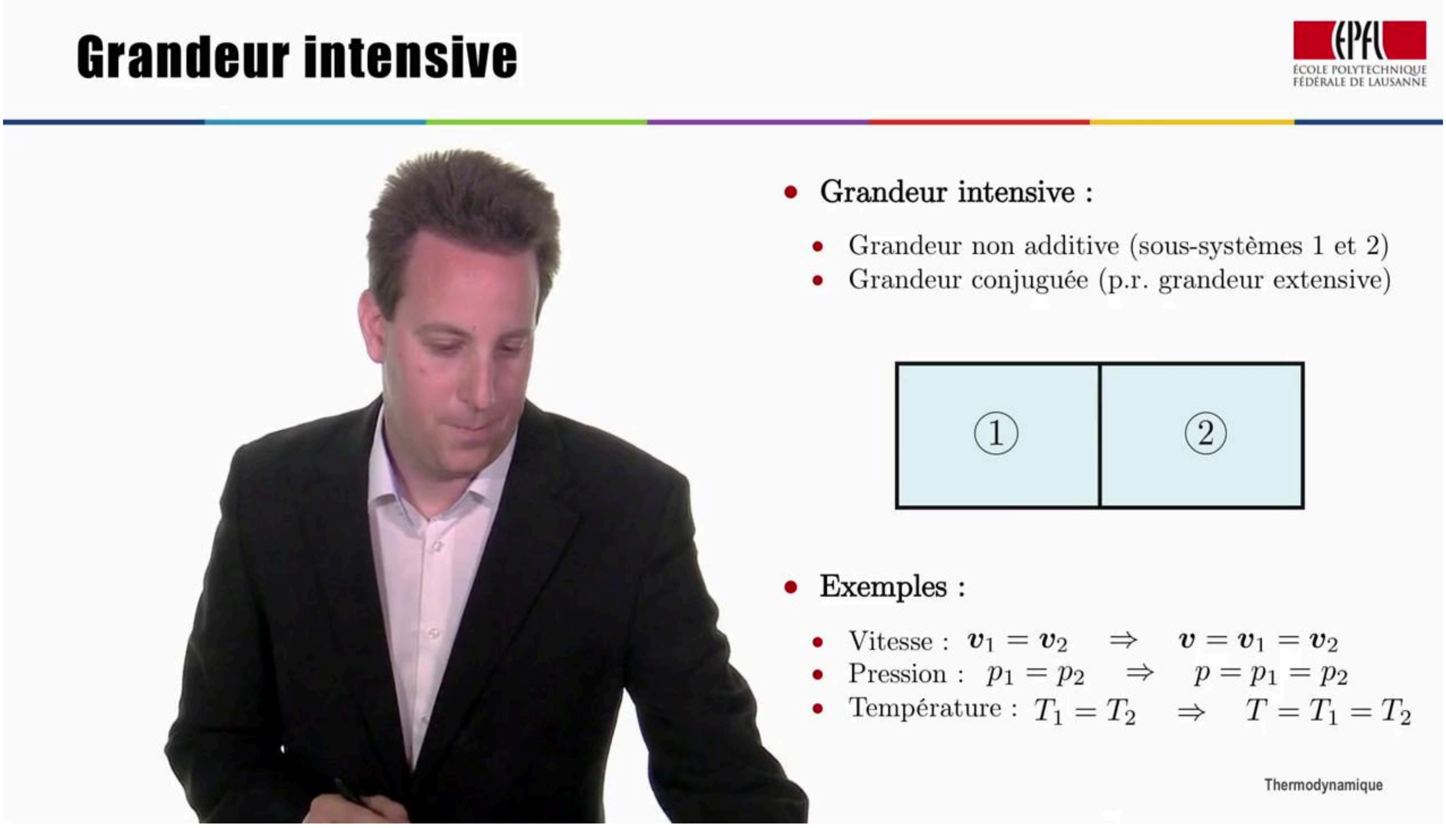


The state of a thermodynamic system is defined by its physical properties. These physical properties are modeled by variables. They are called state variables. The set of state variables completely characterizes the state of a thermodynamic system. This set of variables will be denoted. X1, x2, x3. X4, x5. The number of state variables needed to determine the thermodynamics of a system and the nature of these variables of state will depend on the particular system we want to describe. To describe the thermodynamics of a system, we must also define functions that depend on the state of the system. These functions are called state functions. They are therefore a function of the state variables of the system. These functions F will be functions of X1, x2, X3, x4 and x5.

Notes

Summary

1m 15s

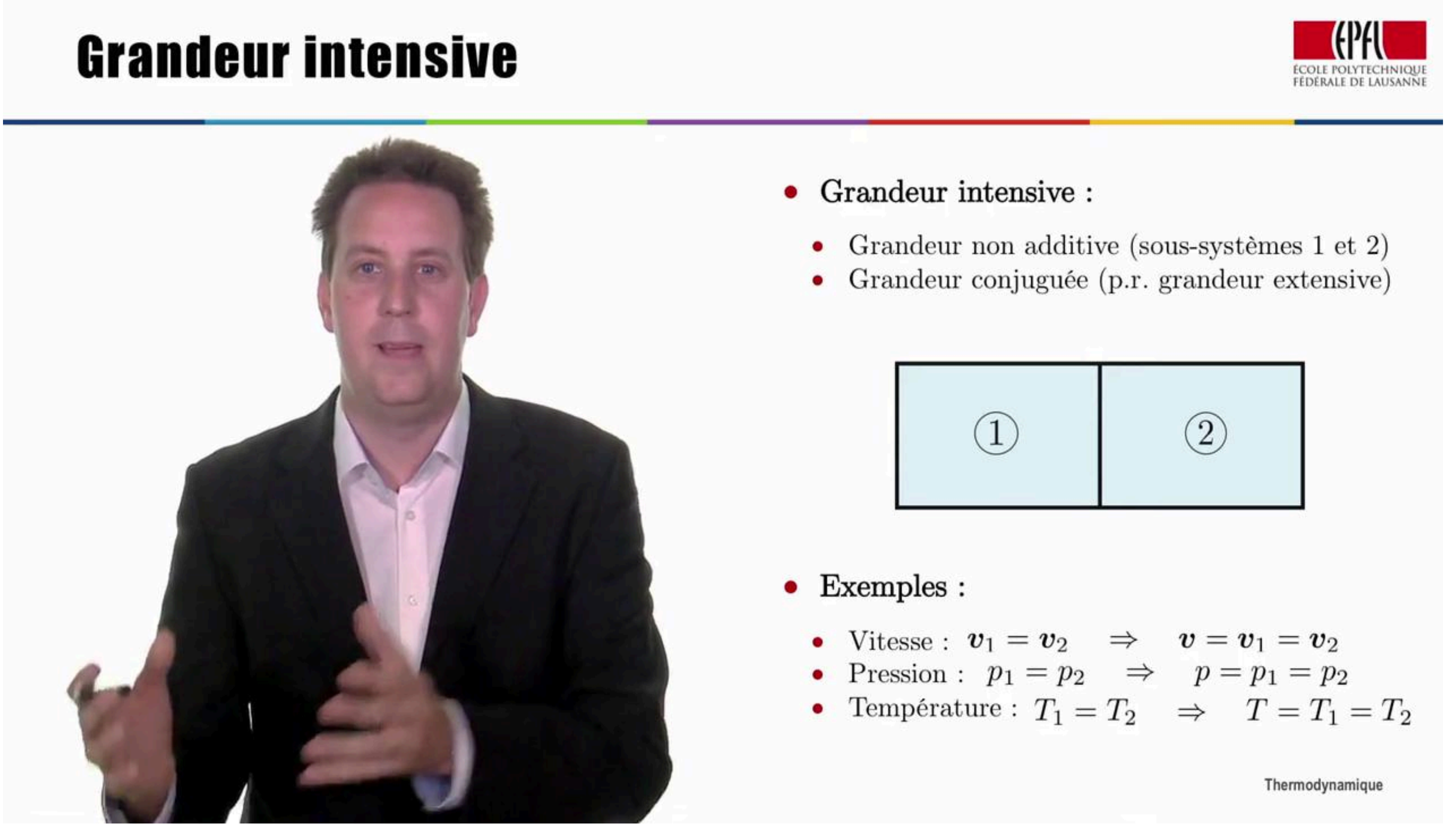


There are different types of thermodynamic quantities. The first type of magnitude that we will to consider, it is the extensive sizes. An extensive quantity is essentially an additive quantity. To account for this activity, we will consider a system formed by two sub-systems one on the left and sub-system two on the right. The quantity is said to be extensive if its value for the system is equal to the sum of its values. For these subsystems, in this case subsystem one and subsystem two. We will now consider some examples. The first example is the mass. The mass m of the system is equal to the sum of the mass M1 of subsystem one and the mass M2 of subsystem two. The second example, is the quantity of motion, the total quantity of motion of the system P and the vector sum of the momentum P one, of the subsystems one and the momentum P2 of subsystem two. The third example is angular momentum, the angular momentum L of the system and the sum of the angular momentum L one of subsystem one and angular momentum L two of subsystem D. And finally the last example is energy. the Energy of the system is the sum of of energy one, subsystem one and energy two of subsystem two.

Notes

Summary

2m 31s

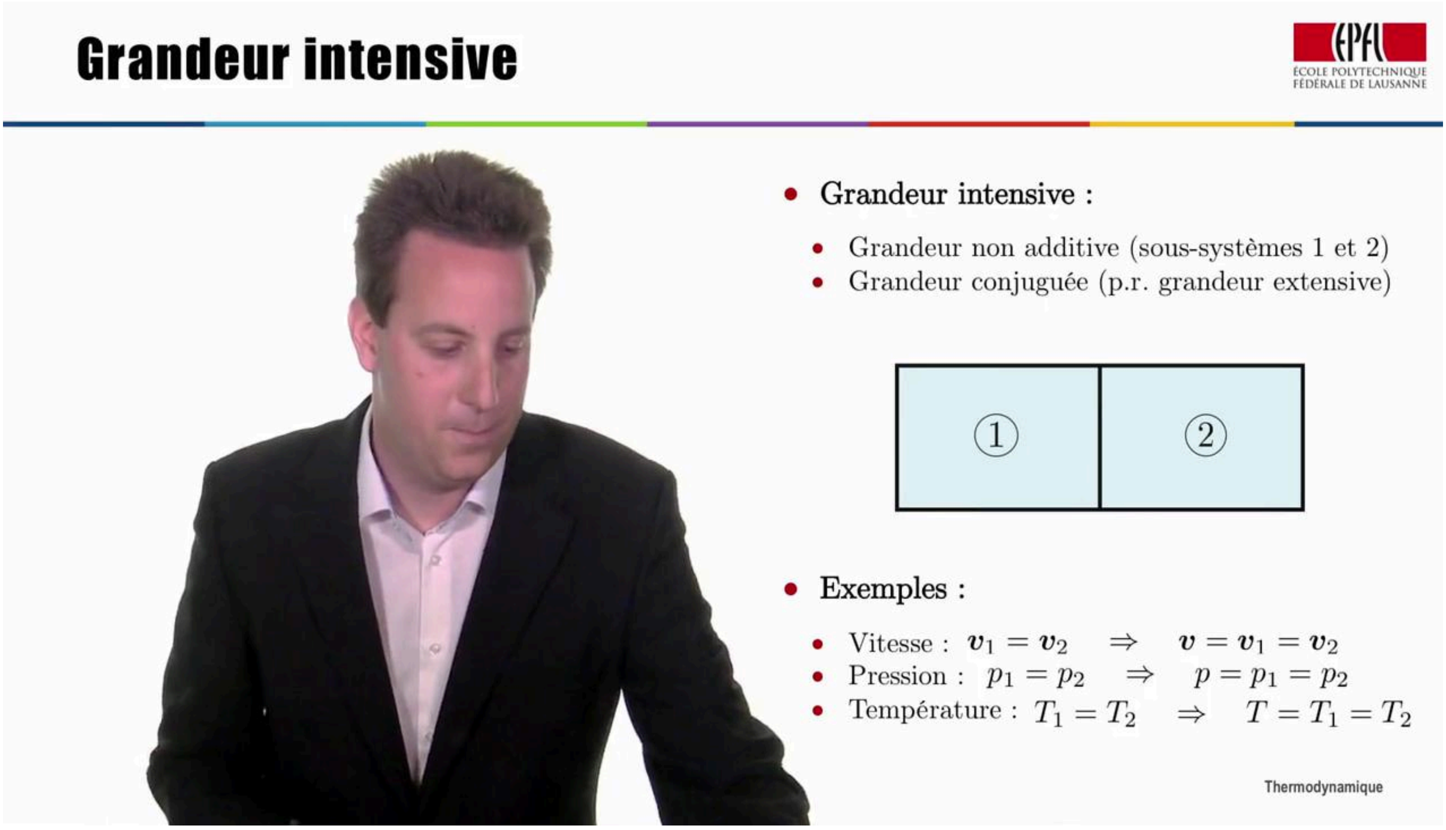


There are extensive quantities and also intensive quantities. An intensive quantity is a quantity which is not additive, unlike the extensive quantity. An intensive quantity is a conjugate quantity. It is conjugated to an extensive quantity. This notion of conjugation is a mathematical notion. The intensive quantity is defined as the partial derivative of the energy with respect to the associated extensive quantity. To account for this intensity, we will again consider a system divided into two subsystems, subsystem one and subsystem two. And we'll take a few examples. First, we will consider the speed. We take the particular case or the speed of the subsystem. A The velocity V1 is equal to the velocity V2 of the subsystem of. In this case the speed of the system. Is equal to the speed of the subsystems. Second example: pressure. We consider again a system for which the two subsystems have the same pressure, i.e. P1 equals P2. In this case, the pressure P is equal to the pressure of the two subsystems. Third example: temperature. Let's assume that the two subsystems and the same temperature T1 equals T2. In this case, the system temperature T1 is equal to the temperature of the two subsystems.

Notes

Summary

4m 17s

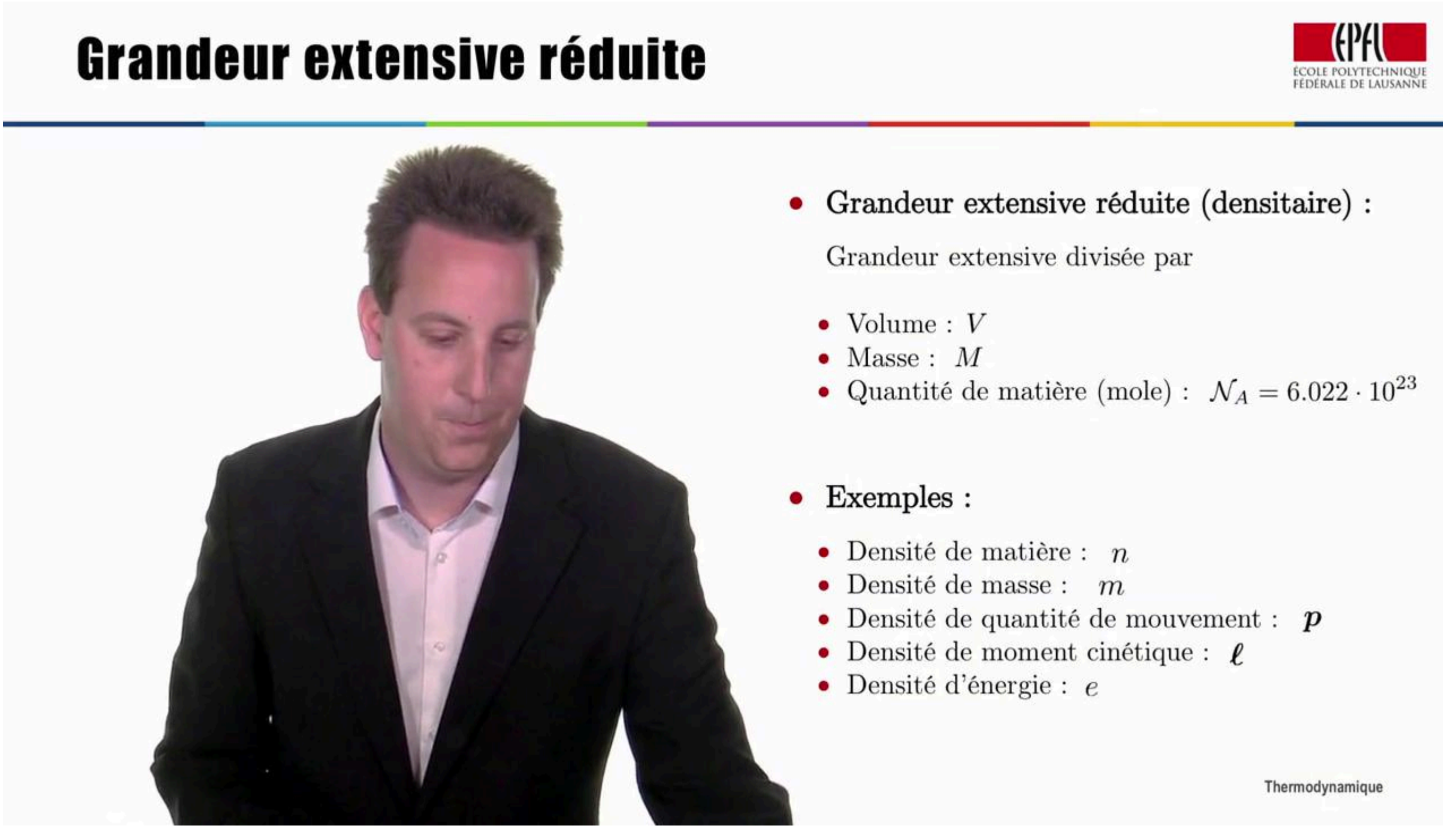


It is interesting to note that for its intensive quantities. The value of the intensive quantity for the system is precisely not equal to the sum of the value. The intensive quantity for both subsystems, since it is the quantities intensive and its intensive quantities are not additive quantities.

Notes

Summary

5m 59s



The third type of size that we now considers the reduced extensive size. A reduced extensive quantity is thus called a density quantity. A reduced extensive size. Is defined as the ratio of a quantity extensive by another type of quantity, which can be either the volume. Either the mass. Let be the quantity of matter, quantity of matter which is defined in mole. The mole is a number. It is the Avogadro number which is 6.022 times ten. Power 23. The reduced extensive quantities. Its denoted by lower case letters to differentiate them from the sizes extensive which are denoted by capital letters. Let's take a few examples. The first example is the density of matter. The density of matter is described by the letter N. Second example, the mass density which is described by the letter M. Third example, the density of quantity of movement which is described by the letter P. Fourth example, the density of angular momentum described by the letter N and finally the energy density which is described by the letter.

Notes

Summary

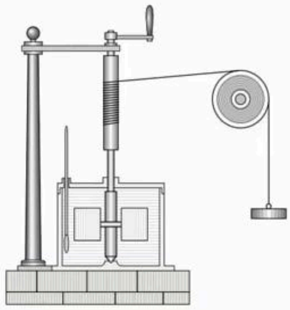
6m 21s

Processus, changement d'état

- **Processus :**

  Interaction extérieure $\Rightarrow$ changement d'état

  - Mécanique $\Rightarrow$ changements d'état de nature mécanique et thermique
  - Thermique $\Rightarrow$ changements d'état de nature thermique et mécanique



Thermodynamique

Thermodynamic processes. Allows to obtain a change of state of the system. Thermodynamics allows to quantify processes that cause changes of state. A process is essentially an external interaction that changes the state of the system. There are two types of processes. First of all, processes of mechanical order and then processes of thermal order. Let's consider an example of a mechanical process. This example is the Joule calorimeter that you have here on the left picture. In this calorimeter, there is a capsule. In the capsule, there is liquid and in the liquid, there is a brewer. The brewer is driven by a mass and the driving of this mass is the mechanical process. The change of state of mechanical nature, is the fact that the brewer is trained. If the brewer is driven. In the liquid, the liquid is viscous. There will be friction, this friction will generate of the dissipation, which will increase the temperature of the liquid. As a result, there will not only be a change of state of mechanical nature, but also a change of state of thermal nature. The second example of a process is a thermal process which is illustrated here on the right.

Notes

Summary

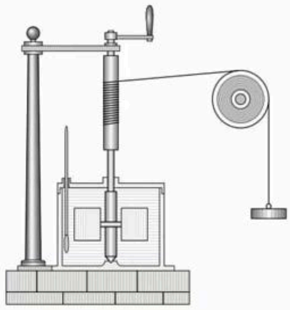
7m 48s

Processus, changement d'état

- **Processus :**

  Interaction extérieure $\Rightarrow$ changement d'état

  - Mécanique $\Rightarrow$ changements d'état de nature mécanique et thermique
  - Thermique $\Rightarrow$ changements d'état de nature thermique et mécanique



Thermodynamique

We have a ball here balloon, a gas is injected, a relatively cold gas and in the sign neck of this balloon, we will inject a little liquid. And then we take the ball in our hands. By thermal contact. The initially cold gas will warm up. So this thermal process of contact will generate a change of state of thermal nature. If the gas heats up, it expands. Therefore, it will push the liquid column up. This will also generate a change of state of a mechanical nature.

Notes

Summary

9m 25s

Dérivées partielles d'une fonction

- **Fonction :**

$f(x,y)$

- **Dérivées partielles :**

$$\frac{\partial f(x,y)}{\partial x} \equiv \lim_{\Delta x \to 0} \frac{f(x+\Delta x, y) - f(x,y)}{\Delta x}$$

$$\frac{\partial f(x,y)}{\partial y} \equiv \lim_{\Delta y \to 0} \frac{f(x, y+\Delta y) - f(x,y)}{\Delta y}$$

- **Exemple :**

$$f(x,y) = x^2 + 3xy \qquad \frac{\partial f(x,y)}{\partial x} = 2x + 3y \qquad \frac{\partial f(x,y)}{\partial y} = 3x$$

Thermodynamique

Let's move on to the last part of this course which is devoted to mathematical analysis. First, we want to define the partial derivatives of a function. This function can for example be a state function. It is the function f that depends on the variables x and y. We can define the partial derivatives of this function with respect to the variables x and Y. When we define partial derivatives, we keep the other variable constant. In terms of rating, we will use circles for the partial derivative to distinguish it from the total derivative which is denoted by one of the rights. Let's start with the definition of the derivative partial function f of the variables x and y with respect to the variable x. For this, we will have to consider a small variation element of x delta x. We will take the limit of delta X tends to zero. From F of x plus delta x and y Greeks minus f of Greek x and y, all divided by delta x. You see that in this definition. The variable plays an essentially passive role. The partial derivative of the function f of x and y with respect to the Greek variable i is defined in a similar way.

Notes

Summary

10m 09s

Différentielle d'une fonction

- Variation de fonction :

$$\Delta f\left(x,y\right) = f\left(x+\Delta x, y+\Delta y\right) - f\left(x,y\right)$$

- Développement mathématique :

$$\Delta f\left(x,y\right) = f\left(x+\Delta x, y+\Delta y\right) - f\left(x, y+\Delta y\right) + f\left(x, y+\Delta y\right) - f\left(x,y\right)$$
$$= \frac{f\left(x+\Delta x, y+\Delta y\right) - f\left(x, y+\Delta y\right)}{\Delta x}\Delta x + \frac{f\left(x, y+\Delta y\right) - f\left(x,y\right)}{\Delta y}\Delta y$$

- Différentielle :

$$df\left(x,y\right) \equiv \lim_{\Delta x \to 0} \lim_{\Delta y \to 0} \Delta f\left(x,y\right)$$

Thermodynamique

It is given by the limit of the small variation element of i Greek Greek delta i which tends to zero of f, of Greek x and y plus Greek delta i minus f of x and y Greek any divided by delta i Greek. Let's take an example. Consider the following function f of x and y. Seven x square. Plus three Greek BIXI. At first, we will calculate the partial derivative of the function f of x and y with respect to x. Let's take the first term. The first term makes x square. The partial derivative of the function f with respect to x that we denote f rounds on X rounds. For the first term, this will simply give us two x's for the second term. We keep i constant, therefore the derivative with respect to x of three x y. When we keep Greek i constant, it is simply three Greek i's. Now we calculate the partial derivative of the function f with respect to the variable i. That is to say that we keep the variable x constant. Therefore, x square is a constant. The derivative of x squared with respect to i Greek gives zero. It does not make any contribution. Now let's take the second term 3XI Greek that we will derive with respect to i Greek keeping x constant. In the end, we get three x's. Now we will introduce.

Notes

Summary

11m 44s

Différentielle d'une fonction

- Variation de fonction :

$$\Delta f(x,y) = f(x+\Delta x, y+\Delta y) - f(x,y)$$

- Développement mathématique :

$$\Delta f(x,y) = f(x+\Delta x, y+\Delta y) - f(x, y+\Delta y) + f(x, y+\Delta y) - f(x,y)$$
$$= \frac{f(x+\Delta x, y+\Delta y) - f(x, y+\Delta y)}{\Delta x}\Delta x + \frac{f(x, y+\Delta y) - f(x,y)}{\Delta y}\Delta y$$

- Différentielle :

$$df(x,y) \equiv \lim_{\Delta x \to 0} \lim_{\Delta y \to 0} \Delta f(x,y)$$

Thermodynamique

The notion of differential of a function. This is a central notion in his thermodynamics courses. The differential of a function. It is an infinitesimal variation of a function. Of several state variables, here two state variables. When both variables vary, we will therefore consider a small variation of the variable x delta x and a small variation of the Greek delta i variable and the variation of the denoted function delta f of x and y Greek. Define it as f of x plus delta x and y Greek plus delta, Greek y minus f of Greek x and y. We will now make a development of the variation of this function In the following developmental analysis, we will introduce an additional term. It is this third term here. Which is the function f of x and y plus delta I that we will subtract in the previous term. We added a term and its opposite. What we're doing now. It is that we will divide the first two terms by Delta X. We will multiply Delta X on all sides. We will proceed in a similar way for the last two terms. We divide them by Greek Delta I and multiply all by Delta I. We can now define. Formally the notion of differential with this infinitesimal variation, we denote it df of x and y.

Notes

Summary

13m 29s

Différentielle d'une fonction

- **Différentielle :**

$$df(x,y) \equiv \lim_{\Delta x\to 0}\lim_{\Delta y\to 0} \Delta f(x,y)$$

$$= \lim_{\Delta x\to 0}\lim_{\Delta y\to 0}\left(\frac{f(x+\Delta x, y+\Delta y) - f(x, y+\Delta y)}{\Delta x}\Delta x + \frac{f(x, y+\Delta y) - f(x,y)}{\Delta y}\Delta y\right)$$

- **Limite :**

$$\lim_{\Delta y\to 0}\Big(f(x+\Delta x, y+\Delta y) - f(x, y+\Delta y)\Big) = f(x+\Delta x, y) - f(x,y)$$

- **Différentielle :**

$$df(x,y) = \lim_{\Delta x\to 0}\frac{f(x+\Delta x, y) - f(x,y)}{\Delta x}\Delta x + \lim_{\Delta y\to 0}\frac{f(x, y+\Delta y) - f(x,y)}{\Delta y}\Delta y$$

$$\boxed{df(x,y) = \frac{\partial f(x,y)}{\partial x}dx + \frac{\partial f(x,y)}{\partial y}dy}$$

Thermodynamique

This is the limit of Delta I which tends to zero and Delta X tends to zero of delta f of x and y Greek. We have just calculated this variation delta f of x and y Greek that can be inserted in this definition of the differential. This is the term that is in parentheses here. What do we have to do now? It is to calculate the limits when delta X tends to zero and Delta I Greek in towards zero, let us look at the first fraction. This fraction depends on Delta I, but it is only the numerator that depends on Delta I Greek and Delta I Greek appears as an argument in the expression of the two functions. The limit of Delta I tends to zero. From this numerator is simply f of x plus delta x and y greek, minus f of x and y greek. Let's consider now. The second fraction. In this second fraction, there is no dependence in delta X. Therefore, the limit of delta X tends to zero. Of this fraction leaves the fraction unchanged. We can therefore express the differential. Which is df x y Greek. As the limit of deltas x tends to zero. From F of x plus delta x and y Greeks minus f of x y greek on delta x the any time delta x more. The limit of delta I tends to zero of f, x and y plus delta i Greek, minus f of Greek x and y, all divided by Greek delta i.

Notes

Summary

15m 17s

Différentielle d'une fonction

- **Différentielle :**

$$df\,(x,y) \equiv \lim_{\Delta x \to 0} \lim_{\Delta y \to 0} \Delta f\,(x,y)$$

$$= \lim_{\Delta x \to 0} \lim_{\Delta y \to 0} \left(\frac{f\,(x+\Delta x, y+\Delta y) - f\,(x, y+\Delta y)}{\Delta x} \Delta x + \frac{f\,(x, y+\Delta y) - f\,(x,y)}{\Delta y} \Delta y \right)$$

- **Limite :**

$$\lim_{\Delta y \to 0} \Big(f\,(x+\Delta x, y+\Delta y) - f\,(x, y+\Delta y) \Big) = f\,(x+\Delta x, y) - f\,(x,y)$$

- **Différentielle :**

$$df\,(x,y) = \lim_{\Delta x \to 0} \frac{f\,(x+\Delta x, y) - f\,(x,y)}{\Delta x} \Delta x + \lim_{\Delta y \to 0} \frac{f\,(x, y+\Delta y) - f\,(x,y)}{\Delta y} \Delta y$$

$$\boxed{df\,(x,y) = \frac{\partial f(x,y)}{\partial x}\, dx + \frac{\partial f(x,y)}{\partial y}\, dy}$$

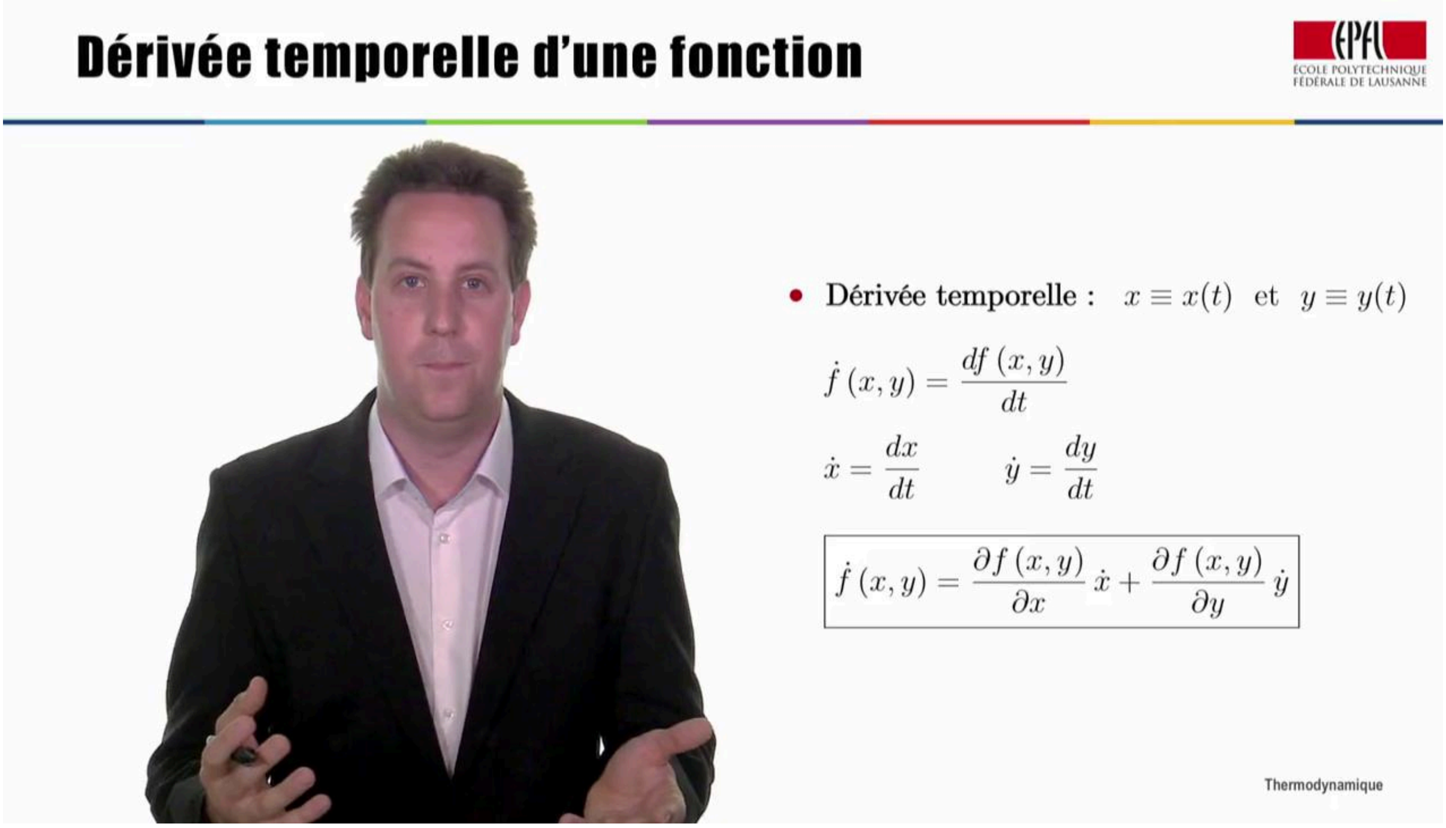
Thermodynamique

Delta is Greek. Taking into account the definition established above of the partial derivative of the function f with respect to the Greek variables x and y, we recognize that the limit of delta x tends to zero of the first fraction. It is simply the partial derivative of f with respect to x. And the debt limit at x tends to zero of delta x x and the limit of delta I Greek tends to zero in the second fraction. This is simply the partial derivative of f with respect to Greek i. And the limit of Delta I tends to zero of Greek Delta I. It is simply Greek. Therefore, we can now identify an explicit relation for the differential df of Greek x and y. This is the partial derivative of f with respect to x that we denote rounds f on rounds x x dx. The more the partial derivative of f with respect to to Greek i that we denote df rounds f on Greek i rounds. Times of the Greeks.

Notes

Summary

17m 12s



Now we have to determine the time derivative. From a function of two variables when these two variables depend on time, i.e. x is a function of t and i is also a function of T. The derivative of the function f of x and y with respect to time is denoted by f from x to y Greek on dt. In addition, we will adopt here and in the rest of this course the writing convention that is usually adopted in mechanics. And that is the following. We will denote this derivative with respect to at time, by a point that we put on the function f point of x and y Greek and thus by definition of the f of x and y Greek on dt. Using the same convention. X point c dx ontt the time derivative of x y with point c of the Greeks on dt the time derivative of Greek I. We can now determine the structure of the derivative time of the function f of Greek x and y is the point of Greek x and y. Will contain two contributions since X and y independently are functions of time. The first contribution is the following. This is the partial derivative of f with respect to x times x. We used here the rule of the derivative of a composition of functions, and the second term, is the partial derivative of f with respect to i Greek for the derivative of Greek i with respect to the time that is Greek point.

Notes

Summary

18m 19s